Technical Article

Reducing Power Loss and Thermal Dissipation in SiC Traction Inverters

George Lakkas

With increasing competition between electric vehicle (EV) manufacturers to develop models with lower cost and longer drive range, power system engineers are under pressure to reduce power losses and improve traction inverter system efficiency, which can improve driving ranges and provide a competitive advantage. Efficiency relates to lower power losses, which affect thermal performance and in turn system weight, size and cost. Demand to reduce power losses will continue with the development of inverters that have higher power levels, especially as the number of motors per car increases, and trucks migrate to pure EV.

Traction inverters have traditionally used insulated-gate bipolar transistors (IGBTs). But with the advancement of semiconductor technologies, silicon carbide (SiC) metal-oxide semiconductor field-effect transistors (MOSFETs) offer the ability to switch at higher frequencies than IGBTs, improving efficiency through resistive- and switching-loss reductions while increasing power and current density. Driving SiC MOSFETs in an EV traction inverter, especially at power levels >100 kW and with 800-V buses, requires an isolated gate driver with reliable isolation technology, high drive strength, and fault monitoring and protection features.

Isolated Gate Drivers in Traction Inverter Systems

The isolated gate-driver integrated circuit (IC) shown in Figure 1 is an integral part of a traction inverter's power delivery solution. The gate driver provides low- to high-voltage (input to output) galvanic isolation, drives the high- and low-side power stages of the SiC or IGBT-based three-phase motor half bridges, and enables monitoring of and protection against various fault conditions.

Copyright © 2023 Texas Instruments Incorporated

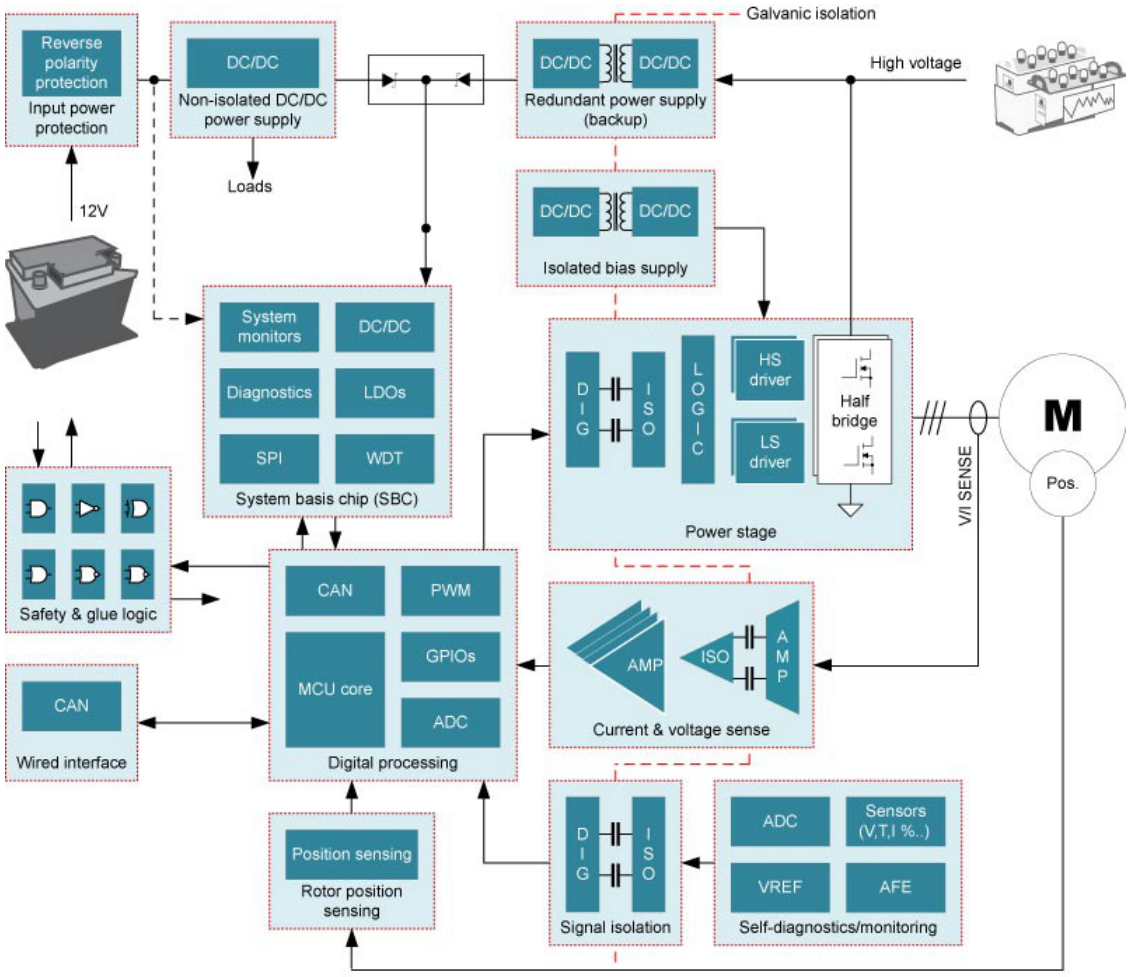

Figure 1. EV Traction Inverter Block Diagram

SiC MOSFET Miller Plateau and the Benefits of a High-strength Gate Driver

For SiC MOSFETs especially, the gate-driver IC has to minimize switching and conduction losses that include turnon and turnoff energy. MOSFET data sheets include a gate-charge characteristic, and on that curve you'll find a flat, horizontal section called a Miller plateau, shown in Figure 2. The more time a MOSFET spends between the on and off states, the more power is lost.

Copyright © 2023 Texas Instruments Incorporated

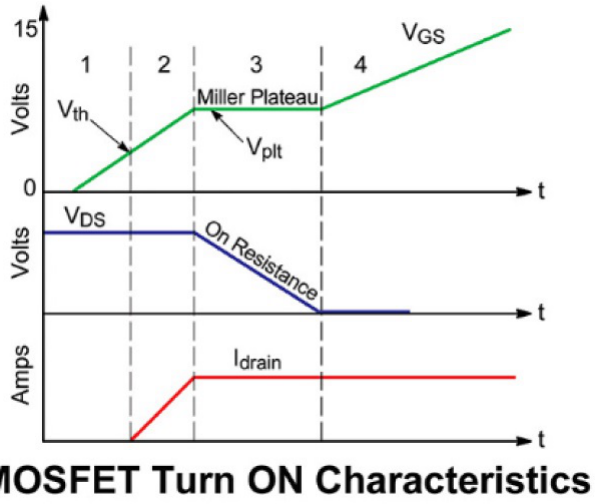

Figure 2. MOSFET Turnon Characteristics and the Miller Plateau

When the SiC MOSFET switches, the gate-to-source voltage (V_{GS}) passes the gate-to-source threshold (V_{GSTH}), is clamped at the Miller plateau voltage (V_{plt}), and stays there because the charge and capacitance is fixed. Getting the MOSFET to switch will require the addition or removal of a sufficient gate charge. The isolated gate driver must drive the MOSFET gate with high current in order to add or remove the gate charge in order to reduce power losses. Figure 1, which calculates the required SiC MOSFET charge that the isolated gate driver will add or remove, shows that the MOSFET gate current is proportional to the gate charge:

$$Q_{GATE} = I_{GATE} \times t_{SW} \quad (1)$$

where I_{GATE} is the isolated gate-driver IC current and t_{SW} is the turnon time of the MOSFET.

For ≥150-kW traction inverter applications, the isolated gate driver should have >10 A of drive strength to switch the SiC FET through the Miller plateau at high slew rates and take advantage of the higher switching frequencies. SiC FETs have a lower reverse recovery charge (Q_{rr}) and a more stable over temperature on-resistance ($R_{DS(on)}$) that enable higher switching speeds. The less time the MOSFET stays in the Miller plateau, the lower the power losses and self-heating.

TI's UCC5870-Q1 and UCC5871-Q1 are high-current, TI Functional Safety-Compliant 30-A gate drivers with basic or reinforced isolation and a Serial Peripheral Interface digital bus for fault communication to a microcontroller. Figure 3 compares SiC MOSFET turnon between the UCC5870-Q1 and a competing gate driver. The UCC5870-Q1 gate driver peaks at 39 A and maintains 30 A of current through the Miller plateau, enabling much faster turnon, which is the preferred result. The faster turnon is also evident by comparing the blue V_{GATE} waveform ramp between the two drivers. At the Miller plateau voltage of 10 V, the UCC5870-Q1 has 30 A of gate-driver current, while the competing device's gate-driver current is 8 A.

Copyright © 2023 Texas Instruments Incorporated

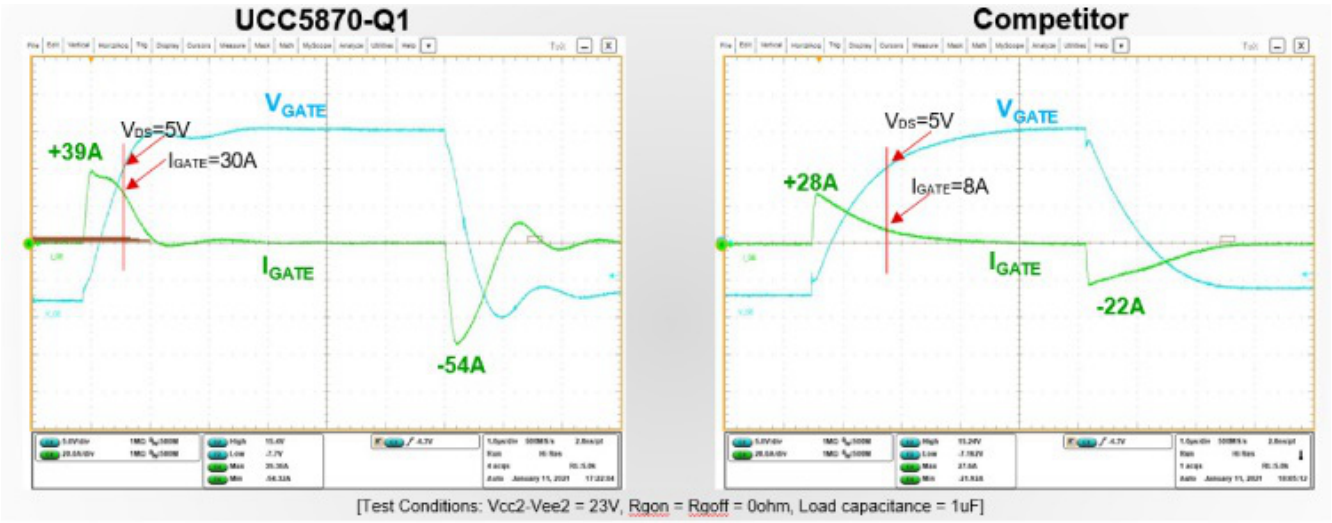

Figure 3. Comparing TI's Isolated Gate Drivers vs. a Competing Device in Turning a SiC FET on

Power-loss Contribution of Isolated Gate Drivers

The gate-driver Miller plateau comparison also relates to switching losses in the gate drivers, as shown in Figure 4. In this comparison, the driver switching loss difference is as much as 0.6 W. These losses contribute to overall power losses in the inverter, and reinforce the need for a high-current gate driver.

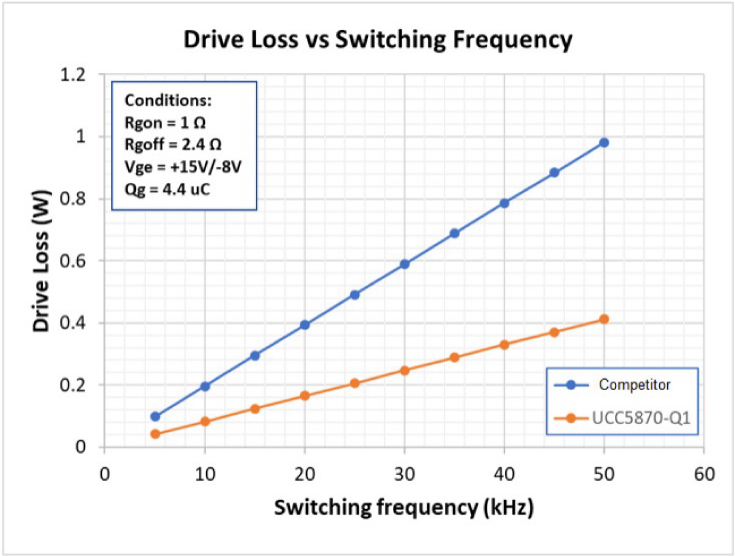

Figure 4. Gate-driver Switching Loss vs. Switching Frequency

Thermal Dissipation

Power losses result in a temperature increase that can complicate thermal management by requiring heat sinks or thicker printed circuit board (PCB) copper layers. High drive strength helps lower the gate driver's case temperature, mitigating the need for more expensive heat sinks or additional PCB ground layers for heat sinking the gate driver's IC temperature. In the thermal images shown in Figure 5, the UCC5870-Q1 runs 15°C cooler because of its lower switching losses and higher drive current through the Miller plateau.

Copyright © 2023 Texas Instruments Incorporated

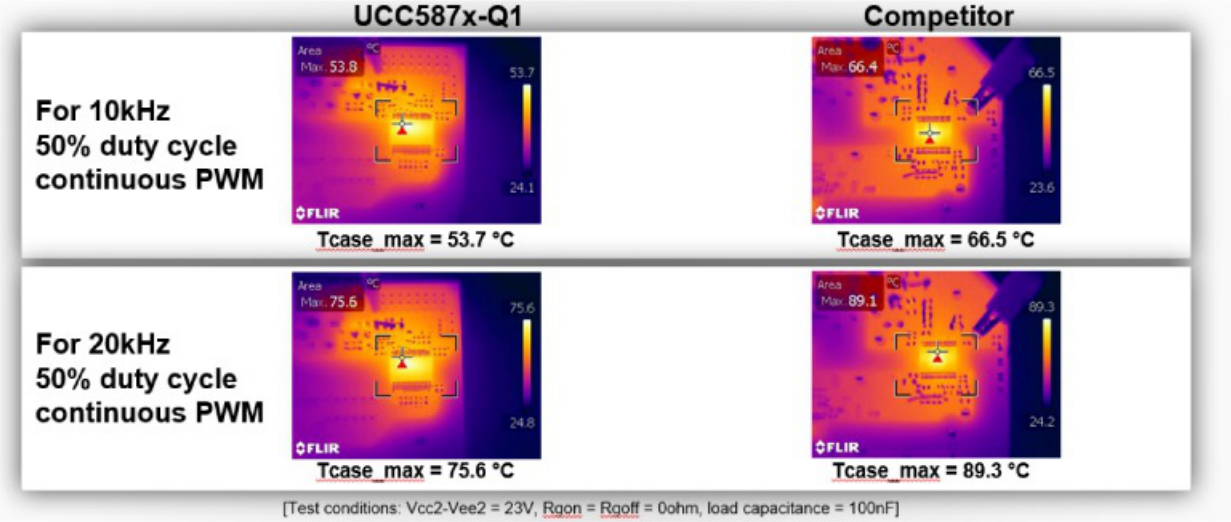

Figure 5. Thermal dissipation of the UCC5870-Q1 vs. a competing gate driver driving a SiC FET

Conclusion

With EV traction inverters increasing in power to over 150 kW, choosing an isolated gate driver with maximum current strength through the Miller plateau can reduce SiC MOSFET power losses and enable faster switching frequencies and therefore higher efficiency which would improve new EV model drive range. TI Functional Safety-Compliant UCC5870-Q1 and UCC5871-Q1 30-A gate drivers come with a host of design support tools to help with implementations.

Additional Resources

- To learn about driving IGBT and SiC power switches, see the e-book, "IGBT & SiC Gate Driver Fundamentals."
- Download the International Organization for Standardization 26262-compliant UCC5870-Q1 gate driver data sheet.
- To learn about designing isolated gate drivers in a traction inverter system, check out the application report, "HEV/EV Traction Inverter Design Guide Using Isolated IGBT and SiC Gate Drivers."
- To learn about designing a traction inverter with a distributed architecture, read the technical article, "Driving Next-Generation EV Systems With a Distributed Architecture."

Copyright © 2023 Texas Instruments Incorporated

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2023, Texas Instruments Incorporated